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Landscape disturbances in the Sumapaz *páramo* area during and after the Colombian armed conflict

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1. Abstract

The Sumapaz *páramo* has been widely studied for its high supply of goods and ecosystem services provided to Bogotá, the central Colombian region and for its role as an ecological network linking the foothills rainforest of the Orinoquia and Amazonas with the montane forest of the Andean highlands. Sumapaz is the largest *páramo* in the world, with 333.420 ha; it is in Colombia's eastern Andean mountain range between 3,250 to 4,230 m.a.s.l. The landscape comprises a wide range of ecosystems, from the *páramo* and *sub-páramo* with montane forests, shrubs forests, and peatlands until the *super-páramo* of alpine tundra landscape with open vegetation of small bushes, frailejones (*Espeletia* sp) and grasslands. During the Colombian internal armed conflict and due to the strategic location of Sumapaz, the guerrillas found refuge in *páramos* and high mountains, generating a series of problems that strongly affected the landscape. They developed activities such as the construction of camps, collection and burning of firewood, deforestation and earthworks to build trenches, roads, guard posts, canalization and damming of water. Currently, the landscape disturbances are primarily due to fires, crops or pastures for livestock.

This study presents a qualitative and quantitative assessment linking how disturbance rates are directly related to the conflict intensity data and the geographic location. We identified landscape disturbances, such as degradation and deforestation generated by direct causes such as military confrontations, antipersonnel mines, and trenches, or indirect causes such as crops, mining, livestock, or forced migration. We used Google Engine to perform the Hansen and Coded algorithm to identify these disturbances from 2001 to 2020 using Landsat TM 4-5, Landsat ETM+ 7, and Landsat 8 OLI satellite imagery. We found a noticeable pattern of higher landscape disturbance during the high-intensity conflict period (2001-2012) compared with a decrease in deforestation rates since the peace talks (2012-2016) and post-agreement period (2016-2020). Studies like the ones presented here can become a tool to understand the reasons behind the conflict and its consequences in highly vulnerable landscape networks and ecosystems, such as the *páramo*.

2. Introduction

2.1. Colombian armed conflict and environment.

The internal armed conflict between guerrilla, paramilitary groups and the government has determined recent Colombian history, and it has extended for over 60 years. Since the 80s, the conflict has been reinforced and funded with the emergence of illicit activities such as drug trafficking, illegal mining, and extensive logging, making the conflict even more harmful for socio-economic and political stability and for the environment. This paper seeks to identify the landscape disturbances, such as deforestation and degradation in vegetation cover and link them with the armed conflict periods in the Sumapaz *páramo* region.

The conflict has modified rural and urban landscapes through changes in society, economic production modes, and land use (Arias, Ibáñez, and Zambrano 2019; Garcia Corrales, Avila, and Gutierrez 2019; Negret et al. 2019; Rettberg, Leiteritz, and Nasi 2014). Most of the Colombian ecosystems have been directly or indirectly war-affected. The consequences have sometimes been paradoxical. During periods of military activity, warfare has unintentionally promoted conservation areas because of landmines or the intense dispute over strategic territories, mainly in the Orinoquia and the Amazon foothills (Clerici et al. 2020; Murillo-Sandoval et al. 2020) (Figure 1). Contrarily, post-agreement activities have increased the pressure on ecosystems, driving deforestation and land cover changes, mostly in fragile ecosystems such as the Amazon Rainforest, where the presence of the government has been scarce or non-existent and where the guerrilla had a strong influence (D. Armenteras, Gast, and Villareal 2003; Dolors Armenteras et al. 2006; 2011; Dávalos 2001; Landholm, Pradhan, and Kropp 2019; Rincón Ruiz, Pascual, and Romero 2013).

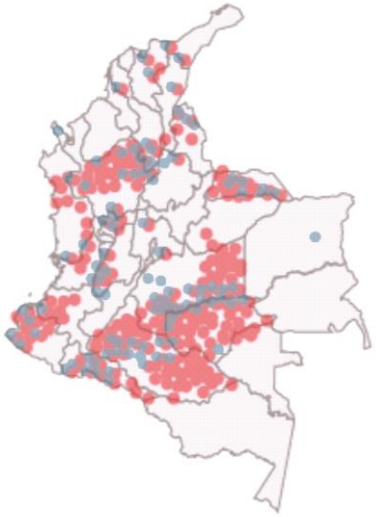

Figure 1. Influence of the conflict and deforestation spots.
Red dots; Areas under influence of the Conflict. *Blue dots;* Deforestation spots.
Source: National Department of Planning, 2018.

2.2. Sumapaz páramo and Conflict.

Sumapaz region (Figure 3) has been characterized by deep-rooted support of left-wing policies related to regional historical processes, such as agrarian struggles and peasant unions. These facts allow understanding the area's vulnerability as a scene, victim and loot of the conflict and its inhabitants as its stigmatized victims by some governmental institutions (Observatorio del Programa Presidencial de Derechos Humanos y Derecho Internacional Humanitario 2002). The region is directly related to a long tradition of agrarian struggles to date to the 1920s. The armed conflict was experienced uniquely in the region since the *Fuerzas Armadas Revolucionarias de Colombia* - FARC guerrilla did not carry out many massive military actions and even less in a sustained manner as they did in other regions. Most of the significant military confrontations took place by the army initiative. However, it must be emphasized that the area suffered the conflict violently, and it was an essential strategic corridor through which FARC moved, manoeuvred and camped.

Considered the largest *páramo* in the world (A variety of alpine tundra ecosystems located above high altitude in the Andes Mountain Range, South America.), this area has high environmental as

well as socio-economic and military relevance for the central Colombian region. Environmentally, the Sumapaz *páramo* provides several ecosystem services to around ten million people, mainly in Bogotá and its surroundings (Buytaert et al. 2006; Célleri and Feyen 2009). The leading service is water supply due to the soil's enormous water retention and regulation capacity (Buytaert et al. 2006; Vuille et al. 2008). Prey (2015) affirms that other services are food and timber supplies from the small trees, shrubs and even *frailejones* (endemic perennial subshrubs) that are mainly useful for the local communities. Additionally, the *páramo* contributes highly to carbon storage (Podwojewski et al., 2006), has high landscape aesthetic and recreational values and has an intangible and spiritual value for the local communities (Anderson et al., 2011). Militarily, the *páramo* was established as the primary security corridor for the FARC through a series of rudimentary roads that directly connected the former demilitarized zone with the outskirts of Bogotá. Since 2001, the National Army has built three high mountain military bases to block the guerrillas' free passage. (Figure 2)

Figure 2. Sumapaz *páramo*. Chisacá Lake.
Photo taken by Mendez, 2021.

The socio-economic and political consequences of the conflict in the Sumapaz *páramo* region have been widely studied; however, the environmental impacts have had less attention. We contribute to the increasing literature on landscape and conflict by performing RS analysis of satellite imagery time series. Do we address two questions: (1) What has been the landscape disturbance from 2001 to 2020 in the Sumapaz region? (2) Which relation has the landscape disturbance rates with the conflict intensity rates during the wartime, negotiation, and post-agreement period? This work presents an integrative and transferable approach for quantifying and assessing landscape changes in areas affected by armed conflicts. Research like this can help policymakers show the environmental impacts within conflict and post-conflict scenarios on the landscape of high-vulnerable ecosystems like the *páramo*.

3. Methods and Data

3.1. Study Area.

The study area is in the central region of Colombia, South America. It is located in the eastern mountain range of the Northern Andes. The study area was defined by the intersection of the Sumapaz National Park protected area with the Cruz Verde-Sumapaz *páramo* boundaries determined by the Alexander von Humboldt Institute (Morales-Rivas et al. 2007). Its geographical coordinates are between LAT_GMS LONG_GMS: North 4° 23' 8.268" N 74° 15' 33.659" W / East

4° 8' 56.364" N 73° 57' 28.799" W / South 3° 32' 56.04" N 74° 31' 4.763" W / West 3° 34' 38.64" N 74° 33' 9.323" W. The study area calculated by ellipsoidal measurement has an extent of 2407 km2. It includes rural areas of the following municipalities; Arbeláez, Cabrera, Gutiérrez, Pasca, San Bernardo, Une and Venecia in the department of Cundinamarca; Guamal and San Luis de Cubarral in the Department of Meta and a large part of the 20th Sumapaz District, belonging to the capital city; Bogotá D.C. (Figure 3).

The Sumapaz *páramo* is a high mountain ecosystem that includes natural habitats between the montane tree line (around 2800-3200m) and the permanent snowline (around 4200m). It is considered the most phyto-diverse tropical-alpine ecosystem on Earth, with about 5000 plant species, 60% of which are endemic (Peyre 2015; Sklenář, Dušková, and Balslev 2011). The *páramo* landscapes comprehend varied topography shapes, such as valleys, plains, plateaus, mountains and foothills. The altitude borders of the ecosystems are not strictly defined and may differ depending on the region. Based on the altitude, ecosystem variations can be found in terms of soils and vegetation cover (Zorro et al. 2005), such as:

• *High Andean Montane Forest (2500m-3200m)*: Has relatively dense forests with high species diversity. It acts as an ecosystem transition from the foggy forest to the *sub-páramo*.
• *Sub-páramo (2800m-3400m)*: Has the predominance of shrubby vegetation and low trees.
• *Páramo (3200m-4000m)*: Contain grass cover, as well as frailejones (*Espeletia* sp), pajonales (*Calamagrostis* sp) and chuscales (*Chusquea* sp) predominate.
• *Super-páramo (<4000m)*: It reaches the lower limit of perpetual snow; the coverage and plant diversity decrease notably, there is a growth of few isolated plants and a predominance of a rocky substrate.

3.2. Armed conflict data acquisition.

The armed conflict data was collected by consulting the database of the Memory and Conflict Observatory (OMC) - National Center for Historical Memory (CNMH, Centro Nacional de Memoria Histórica 2021). The search parameters were from 2001 to 2020, only in the rural areas of the nine municipalities of the study area plus Sumapaz, the 20th District of Bogotá D.C. We measured the conflict intensity using two rates; the number of total victims (injured and causalities) and the number of violent actions per year. For both rates, we compiled data on the following violent acts: homicides, terrorist attacks, massacres, attacks on the population, acts of war, forced disappearances, landmines, and kidnapping. A visual comparison was carried out to correlate armed conflict intensity data with landscape change data.

3.3. Satellite imagery acquisition, pre-processing, processing and disturbance detection.

We imported the (Hansen et al. 2013) Global Forest Change dataset into Google Earth Engine (GEE) to identify the forest change at 30 meters resolution. However, the high coverage of clouds in the study area made imagery selection challenging. Hence, we used Landsat 4-5 TM, 7 ETM+ and 8 OLI satellite imagery scenes covering the study area with less than 30% of cloud cover, provided by the U.S. Geological Survey for the 2001-2020 period. A collection of level-1 terrain-corrected Landsat surface reflectance imagery corresponding to 10 WRS-2 tiles during the 2001–2020 time series were used. We carried out a sequence of filters and data depuration. First, the correction of pixels by proximity and similarity was applied to the original imagery to eliminate misclassified pixels. We performed a visual analysis combining three information bands of each satellite image to form false and true colour images with the Red Green Blue-RGB channels.

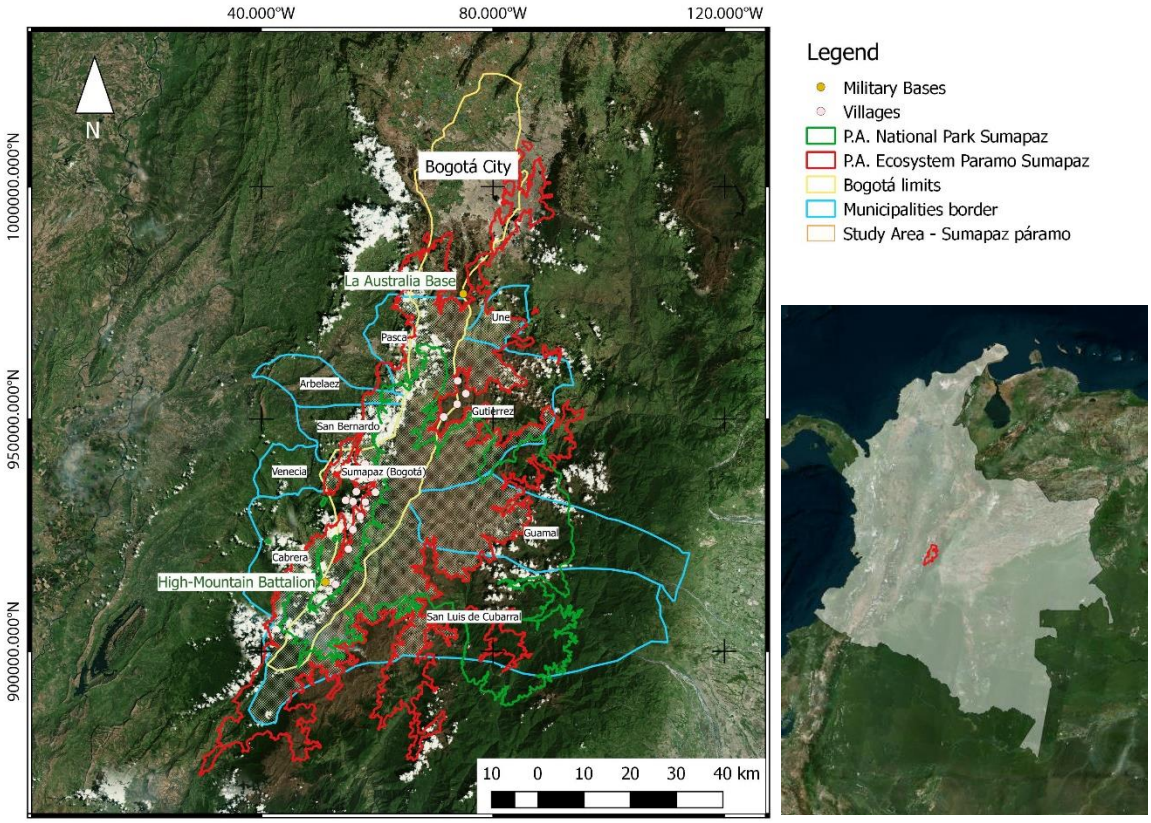

Figure 3. Study area. *Left*; Study Area. *Right*; Location within Colombia. (Own figure)

The analysis was performed by running the GEE platform and using the above mentioned Landsat imagery dataset. We employed the Tasselled Cap wetness index, which merged all Landsat spectral bands and presented a coherent disturbance detection performance. We split the time series into a conflict period (2001–2012) and a peacetime period (2012–2020). For each conflict stage, vegetation disturbance patches were compiled to measure patch metrics, rate, and size. We also performed a disturbance detection analysis within a 5km outer buffer. Then we analyzed the linkages between vegetation disturbance and conflict processes. After GEE analysis, the images were processed in ArcGIS10.1 and QGIS 2.18. Las Palmas.

4. Results

4.1. Landscape disturbance in the Sumapaz páramo.

Landscape disturbance detection in the Sumapaz Region through the entire study period of 2001–2020 determined that 239934.172±38.29 ha (95% confidence interval) of the vegetation/land cover remained stable and 765.82±38.29 ha of forest were disturbed, corresponding to 0.318% of the study area of Sumapaz *páramo*. Across conflict stages, during wartime (2001–2012), we detected 705.66 ha (0,29% of the study area) of vegetation disturbance, during negotiations (2013–2016) 21.29 ha (0.0089%), and during post-peace agreement (2017–2020) 38.66 ha (0.016%). Regarding the landscape disturbance detection in the study area, including the 5km outer buffer we found through the entire study period of 2001–2020 determined that 239320.85±68.95 ha (95% confidence interval) of the vegetation cover remained stable and 1379.1504±68.95 ha of forest were disturbed, corresponding to 0.57% of the study area. Along conflict stages, during wartime

(2001–2012), we detected 1213.179 ha (0,50% of the study area) of vegetation disturbance, during negotiations (2013–2016) 49.81 ha (0.0206%), and during post-peace agreement (2017–2020) 116.15 ha (0.048%). (Figure 4)

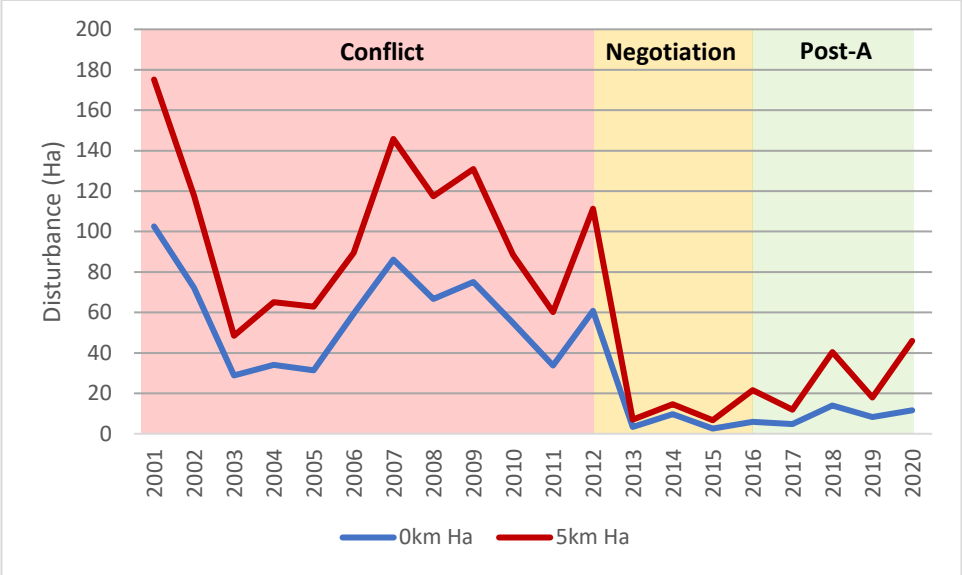

Figure 4. Vegetation Disturbance area in Hectares.
Blue line: Study area limits. *Red line:* 5km outer buffer. (Own figure)

Vegetation disturbance was more evident in 2001, 2007, 2009 and 2012. The disturbance analysis was primarily performed using satellite imagery of December or January due to these months correspond with the dry season, and there is less cloud cover imagery. The dry season is propitious for logging and forest felling by setting fires. The decrease in vegetation disturbance since the negotiations and post peace agreement is more evident in the study area than within the 5km outer buffer in the Sumapaz *páramo* region. The study area, including the PA, experienced less disturbance within their boundaries than the 5 km surrounding buffer outer controlled by FARC during the conflict period. (Figure 5)

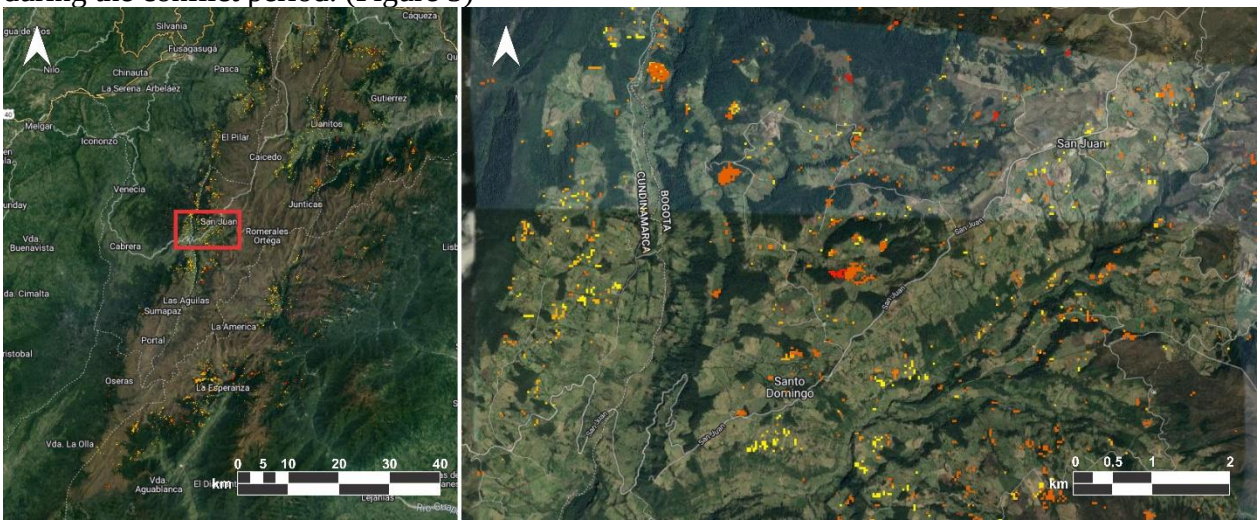

Figure 5. Vegetation disturbance in San Juan de Sumapaz village hotspot.
Left; Study area. *Right;* Zoom in San Juan area. *Yellow pixels;* shorter disturbance – *Red pixels;* longer disturbance.

4.2. Conflict rates in the Sumapaz páramo.

To determine the conflict intensity in the region year by year, we separated the data into two main categories; by the number of victims (Injured, fatalities or affected; 514 in total) and the number of conflict-related cases (520). Victim data were classified into the following categories; number of victims of military actions, selective assassinations and massacres, forced disappearances, antipersonnel mines, and fatalities in combat (80 in total). We identified high rates of victims during the first years of the conflict period (2001-2003), with an average of 116 victims per year. From 2004 to 2012, there was a high decrease even if considerable rates of victims continued to be evidenced, most of them due to sporadic military actions. The rate of victims was less than ¼ compared to the period of high-intensity conflict, with 18 victims on average per year. Then, during the negotiation period, from 2013 to 2016, low rates of victims were found, with an average of 1 victim per year. Finally, after the peace agreement sign, from 2017 to 2021, the number of victims was reduced to practically zero, except for one victim in 2021 due to antipersonnel mines. (Fig 6)

We obtained the total number of violent cases by adding the total cases of War Acts, Selective Assassinations, Attacks on Towns, Terrorist Attacks, Damage to Civil Property, Forced Disappearances, Massacres, Mines, and Kidnapping. Regarding the number of cases, we found a high number of military actions during 2001, 2002 and 2003, with an average of 115 actions per year. Subsequently, from 2004 to 2012, the intensity of the conflict was considerably reduced, with an average number of military actions of 18 cases per year. Then, from 2013 to 2016, low cases rates occurred with an average above 2 per year. Finally, from 2016 to 2021, violent actions dropped drastically to 1 case per year during the post-agreement period. (Figure 6)

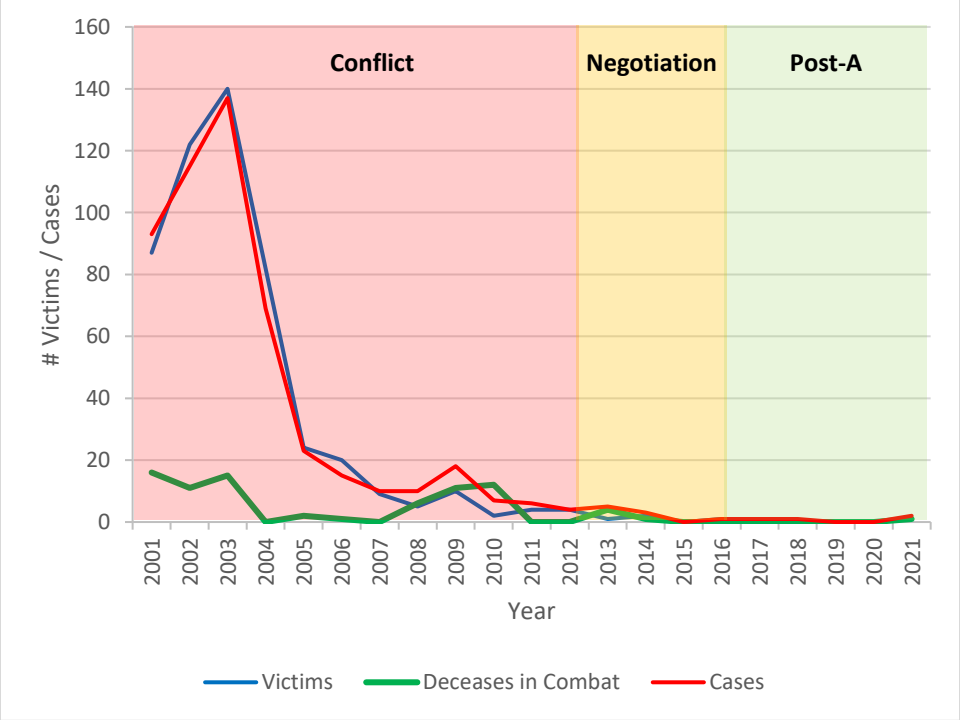

Figure 6. Victims, deceased and war-related cases.

Blue; Total victims (Injured, fatalities or affected). *Green*; Fatalities due to combats. *Red*; Total cases of conflict-related actions.

Source: Memory and Conflict Observatory (OMC) - National Center for Historical Memory (CNMH, Centro Nacional de Memoria Histórica 2021)

5. Discussion and conclusions

In the particular case of the Sumapaz *páramo* area, we can show that there has been a direct and indirect relationship between the conflict intensity data and the data obtained on landscape disturbance. Other regions with higher forest density, such as Putumayo, Caquetá and Catatumbo in the north of Santander (Clerici et al. 2020; Murillo-Sandoval et al. 2020), differ remarkably from the Sumapaz case. In those regions during the high-intensity conflict period, the environment and the landscape have been unintentionally benefited and protected by the armed conflict. In Sumapaz *páramo*, the highest number of landscape disturbances occurred during the most violent years.

We can explain the particular influence of the conflict on the Sumapaz *páramo* landscape by understanding its role during the development of the conflict. At first, the region was a zone of transit and not permanence; troops, supplies, weapons, and even kidnapped people moved there. Years passed, and the 1990s meant a breaking point for the guerrilla's presence. During the failed peace talks between the Colombian government and the FARC between 1998 and 2002, the Sumapaz region gained strategic importance for the guerrilla since it allowed them to directly connect the demilitarized zone of Caguán in the south of the country with the outskirts of the capital, Bogota. This corridor started from Usme and crossed the Sumapaz area and then the Amazon foothills; La Macarena NP, Los Picachos NP and Tinigua NP and ended in Putumayo, in La Playa NP. The guerrillas built a series of highways with heavy machinery and explosives to connect these two areas. These roads and camps broke the natural balance, with the opening of trenches, the felling of flora and the use of growing trees to construct camps and bridges (Uribe, Otero-Bahamón, and Peñaranda 2021).

At the beginning of 2000, the State launched the retaking of Sumapaz region through the Annihilator II operation. It was an enormous military movement where nearly 4,000 soldiers accompanied by the Air Force advanced from different flanks to surround and withdraw the Eastern Block of the FARC, whose control, siege and presence in the area were increasingly marked. After the military operation, the *Alto de Las Águilas*, a strategic plain in the middle of the mountains of the municipality of Cabrera at 3900 m.a.s.l. that until the year 2000 had been controlled by the FARC, became the axis of the operations of the Armed Forces in the Sumapaz. There, in 2001, the High Mountain Battalion was founded to control the region, and the new and controversial presence of the Military Forces throughout the region was launched (Moreno-Rodríguez and Díaz-Melo 2018). Two more military bases are close to the high-mountain battalion; Fenix and Banderas. There are also two more battalions in the northern part of the *páramo*. In 2002 there was a presence of 8 soldiers per inhabitant, being the highest in the country because, in the Sumapaz region, the territorial control requires a significant military presence in a sparsely inhabited area due to its extension. For instance, based on the study area analysis, during the 2001 to 2005, we found disturbance pixels where are located these military infrastructures, including the road built by the FARC (*Troncal Bolivariana* Road from *Tunal Alto* village to *Laguna Hoya Honda*) (Figure 7). Our regional analysis could prove that this infrastructure has impacted the *páramo's* landscape and the vegetation cover, mainly in the southern region of the study area. The construction of the military battalion has generated high resistance from the local communities towards the army presence. The Army, aware of its presence effects, is currently attempting to process its waste adequately. They also have a process of ecological restoration of the *páramo* by cultivating *frailejones* which they have developed with the guidance of the Regional Autonomous Corporation of Cundinamarca, of National Natural Parks of Colombia and the Botanical Garden of Bogotá.

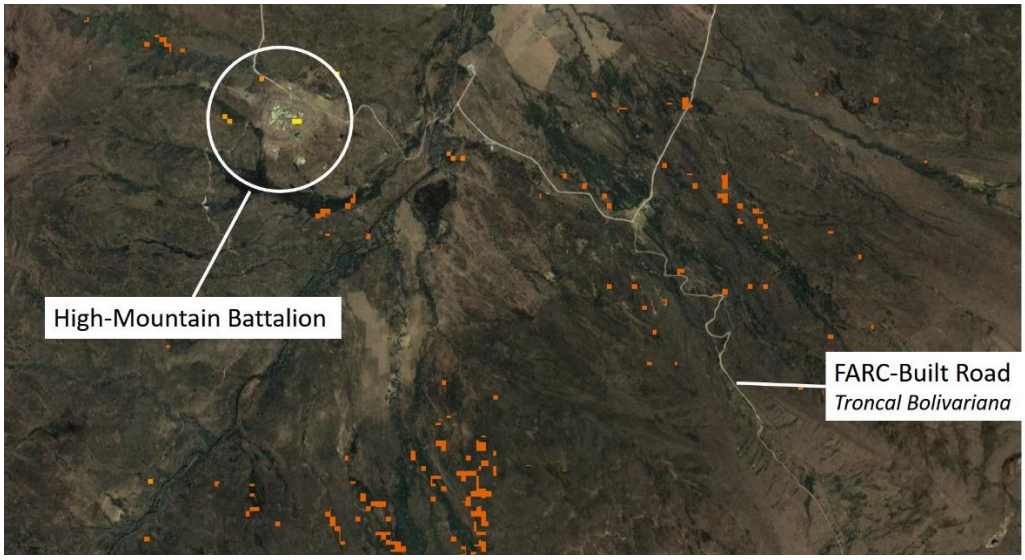

Figure 7. Vegetation disturbance around High-Mountain Battalion and San José village hotspot.
Orange pixels; disturbance patches.

The data showed high-intensity conflict rates at the beginning of the century, especially from 2001 to 2004, and a slight rebound in 2009, both in conflict-related cases and victims. High rates of confrontations, attack populations, terrorist attacks and mainly a high number of victims, whether due to massacres, selective assassinations, anti-personnel mines, or combat, were evident. From 1998 to 2000, the FARC started to build the *Troncal Bolivariana* road to connect Bogotá to the demilitarized zone in the Colombian south-Andes foothills. This construction was stopped when the Army arrived at the zone in 2000. From 2000 to 2004, the Army built a significant military infrastructure (High-mountain Battalion, trenches, heliports, etc.). Additionally, built a few roads around the military base, and partly completed the road started by the FARC. These conflict peaks do not overlap in time with the data thrown off the landscape disturbance peaks, going both rates in opposite directions. When the Army arrived at the area, the landscape disturbance rates decreased rapidly, which can be explained because, during this high-intense conflict period, all the civil activities and the FARC´s activities had to stop suddenly due to the intense confrontations and security reasons. A considerable local population was forced to displace to other areas within the *páramo* or to other regions.

Then, in 2004, the Army started to control the area. The violence rates decreased significantly, and the local communities could slowly retake their normal activities, including farming and cattle ranching. The Army consolidated its military infrastructure and presence in the zone and finished the construction of the road. These activities led to an inconstant increase with ups (2007, 2009, and 2012) and downs (2005, 2008, and 2011) in the landscape disturbance rates. However, the alarming disturbance rates presented at the beginning of the decade did not present again.

We can suggest that peaceful times have prompted considerably to conserve and restore the *páramo* landscape. Since starting the negotiation period in 2012, the decrease in landscape disturbance and violence rates has been noticeable. Partly is due to the Government having a higher institutional presence in the region and, with the help of the local communities, carrying out reforestation and conservation programs. However, there is still concerning the problem of occupation and

construction that these groups generated. It is added to the socioeconomic problem of marginalization of the peasants, the difficulty for the production and commercialization of their products, and the concentration of rural property towards strategic ecosystems or marginal urban areas due to the pressure from these groups, affecting the activities of rural society (Ospina-Rodriguez 2003).

The disturbance data within the 5km outer buffer area refers mainly to forested areas and valleys located below 2900m, which explains why in this buffer, the disturbance indices are much higher than within the study area that is above 2900 meters. These valleys have a higher density of vegetation cover, comprising mainly Andean cloud forest, montane forest, and *sub-páramo* forest ecosystems with higher forest cover and less rocky and grassy surface than the *páramo* and super-*páramo* ecosystems. The influence of the armed conflict in this area is much more noticeable through remote sensing methods due to the higher forest cover density. Also, within the buffer inhabits a larger human population because this area has better weather and living conditions, making these areas more prone to changes in the landscape due to human influence.

Besides the direct influence of the armed conflict, we could hypothetically infer that indirect causes of the conflict have influenced the landscape disturbances. The forced and non-forced displacement population coerced the population to look for new and higher areas to live and crop. This displacement extends the agricultural border regarding altitude, promoting a quick extension of the crop border towards higher areas of the *páramo*. Nowadays, it reaches the border between *páramo* and *super-páramo* in some areas, where the severe climate and unfertile soils create the limit. Pasture practices, including alternating phases of burning and grazing, are relatively less impacting than agriculture; however, they affect vegetation and soils as well (Molinillo and Monasterio 2002). Peyre (2015) affirms that significant impacts of burning include losses of biodiversity, impoverishment of the soils and regressive vegetation succession. For instance, from shrublands to grasslands and then to dry meadows or rocky lands. Grazing carried out by cows or sheep causes soil contamination and affects the plant species variety (Hofstede et al., 2003; Peyre, 2015).

Most studies about the influence of the Colombian armed conflict on the landscape and the management strategies are carried out nationally (Cabrera et al. 2020; Armenteras et al. 2013; Clerici et al. 2020; Mendoza 2020; Sánchez-Cuervo and Aide 2013; Schoenig, Dupras, and Messier 2020; Prem, Saavedra, and Vargas 2020). Given the extension and the unique particularities of the *páramo,* local and regional studies are needed. The main obstruction of *páramo* studies is the lack of deeper analysis involving all the drivers and stakeholders. Although the difficulty and restriction in accessing specific military data such as the location and date of bombing and confrontations, other methods could be performed to accurately prove the conflict's influence on the landscape. For instance, the use of remote sensing analysis in order to link the influence of the FARC-built road and the military infrastructure proximity with the disturbance patches, as well as the detection of craters and landmines using satellite imagery analysis and Airborne laser Scanning; LiDAR radar (Light Detection And Ranging). The involvement of the local communities' perceptions in future research through PPGis methodologies could also help prove the direct and indirect link between conflict and landscape in the study area.

The local communities play a relevant role in shaping and maintaining the Sumapaz *páramo* landscape, whether in peace or wartimes, principally in the *sub-páramo* and *páramo* belts, hence the importance of joint work between local communities, regional and national authorities, the

National Army, the academy and environmental institutions. During post-agreement times, the landscape disturbances rates have improved considerably, mainly due to the Peasant Unions' conservation and restoration efforts (e.g. *Sintrapaz* and *Consejo Local Mujeres de Sumapaz*). However, the human pressure activities such as; massive tourism, the extension of the agricultural border, population growth, mining, and extensive cattle ranching, could emerge as a threat to the *páramo* and may intensify and speed up the ecosystem degradation (Balslev and Luteyn 1992; Hofstede et al. 2003; Peyre 2015).

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